The effects of cold weather upon train resistance and tonnage rating

Edward Charles Schmidt, Franklin Wales Marquis

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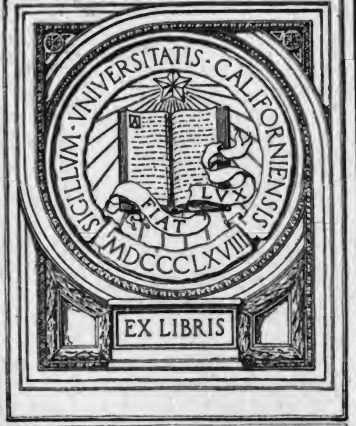

JUL 8 1912
EXCHANGE

UNIVERSITY OF ILLINOIS BULLETIN

Vol. IX MAY 27, 1912 No. 29

[Entered Feb. 14, 1902, at Urbana, Ill., as second-class matter under Act of Congress of July 16, 1894]

BULLETIN NO. 59

THE EFFECTS OF COLD WEATHER UPON TRAIN RESISTANCE AND TONNAGE RATING

BY

EDWARD C. SCHMIDT

AND

F. W. MARQUIS

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ENGINEERING EXPERIMENT STATION

BULLETIN No. 59 MAY, 1912

THE EFFECTS OF COLD WEATHER UPON TRAIN RESISTANCE AND TONNAGE RATING

BY EDWARD C. SCHMIDT, PROFESSOR OF RAILWAY ENGINEERING AND F. W. MARQUIS, ASSOCIATE IN RAILWAY ENGINEERING

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THE EFFECTS OF COLD WEATHER UPON TRAIN RESISTANCE AND TONNAGE RATING

I. Introduction

The resistance offered by railway trains is greater in cold weather than it is under ordinary summer temperatures. Evidence of this fact will occur to all who are concerned with train operation, and its recognition has led to the practice of reducing tonnage ratings of locomotives during cold weather. This practice is almost universal among the railroads operating in the northern part of the United States and in Canada. On the few roads, running in this territory, which do not reduce ratings during cold weather, it seems probable that the ordinary summer ratings are lower than they might well be and that consequently the locomotives have a reserve tractive effort great enough to permit them to handle these same ratings throughout the winter months.

Any method of tonnage rating should recognize the three important variables which modify train resistance, viz., speed, average weight of the cars, and air temperature. The influence of speed is quite generally allowed for in establishing ratings and it is becoming more and more customary to make distinctions in rating on account of differences in car weight. The influence of the third variable, air temperature, may be as great as that of either speed or car weight, and it is proper that it should have received as general consideration in establishing winter ratings as has been accorded.

Recognizing the importance of the subject, the Railway Engineering department of the University of Illinois, two years ago, undertook tests to determine the increase in train resistance due to cold weather, and this work is still in progress. It is hoped that it may result eventually in information sufficiently specific to indicate the law according to which train resistance* and air temperature are related, and thereby to enable the reductions in rating for different air temperatures to be determined with greater certainty than is now possible; for, as will appear later, there is at present considerable diversity of practice concerning such tonnage reductions. These tests are still far from being

*Throughout the paper, train resistance means the force needed to keep the train moving at uniform speed on straight, level track and in still air. This force is expressed in pounds per ton of train weight.

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completed and the data in hand do not yet warrant definite conclusions. The work has, however, gone far enough to develop some rather interesting results and it is the purpose here to present this evidence and also to present a summary of the current practice of American railroads in reducing tonnage ratings during cold weather.

The material here presented was first published in substantially the same form in the Proceedings of the Central Railway Club for January, 1912, and is reproduced by permission. The tests referred to were made possible by the courtesy of the officers of the Illinois Central Railroad.

Before presenting the experimental results, it may be helpful to examine the ways in which low air temperatures may affect tonnage rating. In establishing a rating, the purpose is to equate locomotive tractive effort and the total resistance of the train, i. e., to determine a train whose gross resistance shall equal the available tractive effort. Anything, therefore, which decreases tractive effort or which increases resistance will necessitate a reduction in rating. A drop in air temperature does both these things. Cold weather decreases tractive effort by decreasing the capacity of the locomotive boiler. This it does in two ways—first, by increasing the amount of heat lost by radiation, and second, by lowering the temperature of combustion. At low speed the reduction in boiler capacity by increased radiation probably does not amount to more than two or three per cent even in very cold weather. The decrease in combustion temperature must be so small as to be negligible in its effects on steam production. Some slight decrease in the efficiency of the performance within the cylinders probably also ensues in cold weather, but data do not exist to enable us to evaluate this effect. Cold weather further decreases tractive effort by increasing the machine friction in all the locomotive bearings. Since, however, the total machine friction is itself not generally more than eight or ten per cent, when maximum tractive effort is being developed, it is apparent that even considerable variations in this friction cannot greatly affect tractive effort. Taking all these facts into consideration, it seems likely that cold weather does not greatly reduce the tractive effort of locomotives, and that, consequently, it does not necessitate radical reductions in rating in so far as its effect upon the locomotive itself is concerned. Probably a reduction in rating of four or five per cent, even with air temperatures as low as 0°F.,

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is sufficient to allow for the reduced tractive effort of the locomotive.

The influence of cold weather in increasing total train resistance is, however, greater than its influence on tractive effort. Under the conditions prevailing at ruling grades, total train resistance is made up of net resistance as above defined, together with resistances due to grade, to acceleration, and to curvature. Of these four elements of resistance only the first—the net resistance on straight level track at uniform speed—is at all affected by temperature. At the speeds at which freight trains pass ruling grades, this net resistance is composed almost entirely of those resistances which develop at the wheel tread and the resistance developed in the car journals. The former we shall call rolling resistance and the latter journal resistance. When the temperature of the air falls below the freezing point, the moisture in the road bed freezes and the whole track structure becomes less yielding. It seems reasonable to expect that under these conditions the rolling resistance will be different from what it is in summer weather. Whether it is greater or smaller does not appear, although there are some reasons for supposing it to be less on "frozen track." Whether it is greater or smaller need not concern us here, for it is altogether likely that at the speeds prevailing at ruling grades this rolling resistance is much less than the other element of resistance, viz., the journal friction. It is in journal friction, therefore, that we must seek for the explanation of the effect which cold weather is known to produce upon train resistance and consequently upon tonnage rating.

A brief review of the actions within the car journal may serve to make clearer the way in which temperature affects the journal resistance. In the journals of a car which has been standing, the oil film has been broken through and the journal and brass are probably in direct contact. The temperature of the oil and of all the bearing parts is the same as that of the air, and the lower this temperature, the more viscous is the oil. As the car starts and the journal turns, oil is brought up from the waste below and the film of oil begins to establish itself. Until this oil film is established over the whole journal, the friction is high and gives rise to the great starting resistances which prevail at this time. As the journal continues to turn, the oil and all bearing parts begin to warm up, due to the heat devel-

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oped by the bearing friction. As the temperature increases, the viscosity of the oil diminishes and the resistance decreases. The temperature of the bearing continues to increase until the rate of heat production within the bearing equals the rate at which the heat is dissipated from the box and other parts, such as the axle. At this point, the bearing temperature becomes constant and the resistance reaches its minimum value and here remains. This dissipation of heat is accomplished by the air moving over the box and axle, and the rate of heat dissipation varies almost directly with the amount of the difference between the temperature of the bearing and the temperature of the surrounding air. To maintain a certain rate of dissipation of heat the *journal* temperature may be lower therefore in cold weather than in warm weather, the temperature of equilibrium attained by the journal is consequently lower in cold weather than in warm weather, and the minimum viscosity of the oil is greater. On these accounts we are prepared to find that the minimum resistance attained in cold weather is greater than in warm weather.

These statements are exemplified by the following record of journal temperatures obtained by the use of the University of Illinois dynamometer car:*

Test number	1094	2007
Average air temperature—degrees F	63	9
Approximate average test speed—m. p. h.	16	15
Maximum temperature attained by test car journal—degrees F	116	98

These tests differ chiefly in the air temperature. In the test on the colder day the temperature of equilibrium attained by the journal is 18° less than that attained on the warmer day.

In another series of tests in which the journal temperature was measured, the resulting average maximum journal temperatures attained during the tests were about 125°, 137° and 145° for constantly maintained speeds of 10, 20 and 30 miles per hour, respectively. In this case the temperature is derived from a journal of one of the cars in the test train. This car weighed 101,000 lb. and was equipped with 5 in. by 9 in. journals. The air temperature during these tests varied from 62° to 90°. These values serve to show the temperatures attained in a heavily loaded journal and also to show the influence of speed on these temperatures.

*This car is equipped with a recording thermometer, the bulb of which is inserted in a hole drilled in the body of one of the journal brasses. This instrument makes a continuous record of journal temperature. The car weighs 58,000 lb., and is equipped with 4¼ in. by 8 in. journals

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II. Results of Experiments

Two years ago the Railway Engineering department of the University of Illinois completed a series of tests* to determine the influence of car weight on resistance. These tests were intended to show only the resistance prevailing in summer weather in order that they might serve as a basis for normal or "summer ratings." Tests made during cold weather have therefore been eliminated from the results. These results are here presented as Fig. 1 merely to offer a basis of comparison. In deriving the curves of Fig. 1 it was necessary to produce for each test such a curve as is shown in Fig. 2 in which the relation between speed and resistance is indicated. Fig. 2 shows the values for resistance at various speeds for test 1027 made in July, 1908, during which the air temperature varied from 64° to 80°. In such a diagram a definite relation between resistance and speed is obvious and no difficulty was experienced in drawing a curve to represent fairly this relation. In these respects Fig. 2 is quite characteristic of the entire series of 32 tests which led to the conclusions embodied in Fig. 1. It should be borne in mind that these tests were made in warm weather.

As the tests progressed, however, and cold weather was encountered, the plotted values of resistance and speed exhibited no such obvious relation. Fig. 3 shows the resistances at various speeds obtained from test 1041, the first test made in cold weather. This test was made on October 31, 1908 and the air temperature varied from 30° at the beginning to 42° at the end of the test. If there is a definite relation between resistance and speed for this test, Fig. 3 certainly does not disclose it and it would require considerable hardihood to try to draw a curve for the points there shown. The attempt to discover a reason for the discordance among resistance values disclosed in Fig. 3 by a comparison of the conditions prevailing in test 1041 with the conditions of the preceding tests, made it clear that this test differed chiefly in being run during cold weather. The explanation was sought in this fact.

In Fig. 3 the resistance values, for speeds in the neighborhood of 15 miles per hour, vary from 8.9 to 12.6 lb. per ton, and similar variations occur at other speeds. If cold weather causes these variations, it does so through its influence on journal temperature. It was conceived, therefore, that the variations were

*Freight Train Resistance: Bulletin 43 of the Engineering Experiment Station of the University of Illinois.

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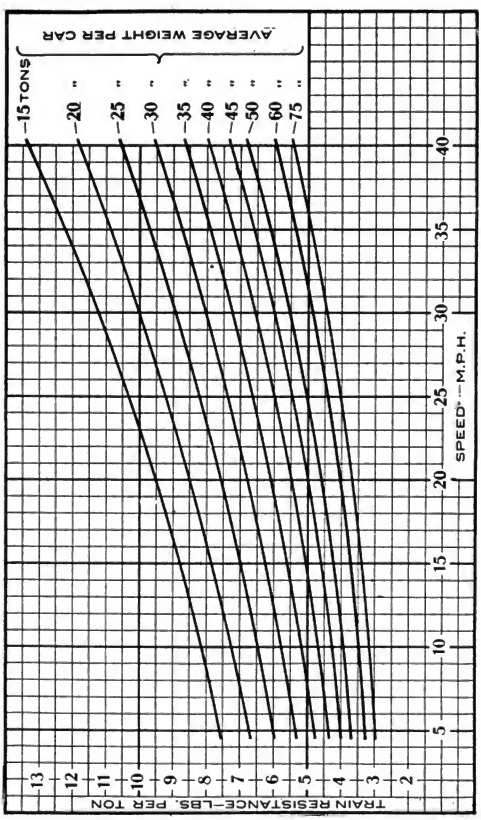

FIG. 1. SHOWING THE RELATION BETWEEN TRAIN RESISTANCE AND SPEED FOR TRAINS COMPOSED OF CARS OF VARIOUS AVERAGE WEIGHTS—APPLICABLE IN SUMMER TEMPERATURES ONLY

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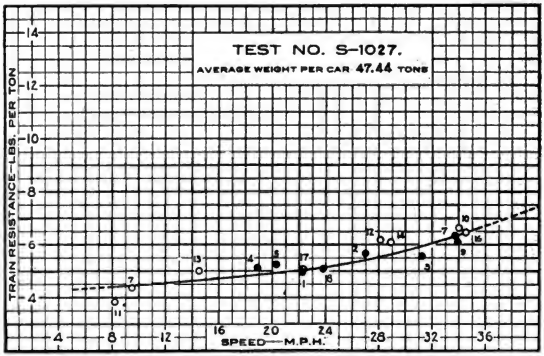

FIG. 2. SHOWING THE RELATION BETWEEN RESISTANCE AND SPEED FOR TEST 1027—AIR TEMPERATURE VARIED FROM 64° AT THE BEGINNING TO 80° AT THE END OF THE TEST

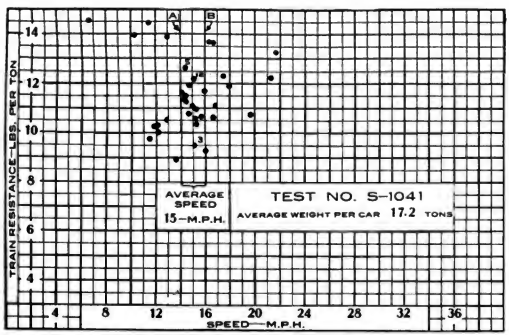

FIG. 3. SHOWING THE RELATION BETWEEN RESISTANCE AND SPEED FOR TEST 1041—AIR TEMPERATURE VARIED FROM 30° AT THE BEGINNING TO 42° AT THE END OF THE TEST

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due to differences in journal temperature, and that these differences were, in their turn, due to the fact that most of the points* in Fig. 3 applied to the period during which the journals were warming up. In other words, it was assumed that cold weather had unusually delayed in this test the time at which the temperature of equilibrium of the journal became established.

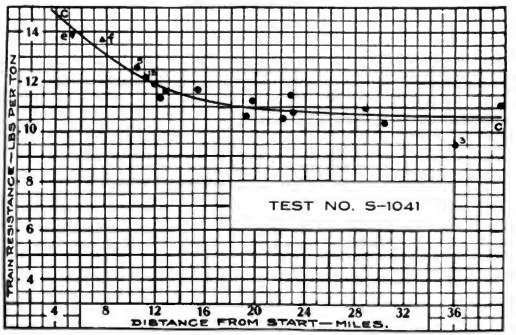

FIG. 4. SHOWING THE DECREASE IN RESISTANCE AS THE TRAIN OF TEST 1041 PROGRESSES. THE RESISTANCES APPLY TO A SPEED OF ABOUT 15 MILES PER HOUR

If these assumptions are correct, it might be expected that a diagram showing the resistance values and the corresponding journal temperatures would disclose their intimate relation. No record of journal temperature was available at this time and it was consequently impossible to produce such a diagram. If, however, the journal temperature was varying, it must have been increasing as the train moved further and further from the starting point, and it was concluded that if, for each point on the road at which resistance had been determined, its value were plotted with respect to the distance of that point from the beginning of the run, such a plot would reveal a regular variation of resistance with distance due to the influence of distance upon

*Each point in this and succeeding diagrams represents the resistance value applying to a particular position of the train upon the road. It may define the momentary resistance as the train passes a particular point, or it may define the average resistance during the time the train passes a short track section.

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journal temperature. It was hoped that such a diagram would offer an explanation of the discordance among the values shown in Fig. 3. This assumption was tested in the following manner:

On Fig. 3 the two lines A and B were drawn embracing all points whose speed values lie between 14 and 16 miles per hour. All points lying within the belt defined by lines A and B pertain, therefore, to speeds which are not far from 15 miles per hour. The resistance values of the points lying within this zone were next plotted as Fig. 4, in which vertical distances again denote resistance, and horizontal distances represent miles run from the starting point. The points which in zone AB of Fig. 3 have the highest resistance values are found in Fig. 4 near the beginning of the run, whereas those having the lowest resistance values fall at the end of the run, and in general the points* in

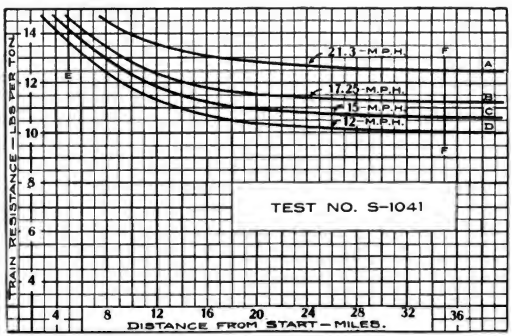

FIG. 5. SHOWING THE DECREASE IN RESISTANCE AS THE TRAIN OF TEST 1041 PROGRESSES—THE CURVES APPLY TO FOUR DIFFERENT SPEEDS

Fig 4 so arranged themselves that their resistance values constantly decrease as the distance increases. A few of the points in Fig. 4 are numbered. These numbers in Fig. 3 denote the corresponding points. Bearing in mind the facts that all values apply to the same train and to approximately the same speed, it

*Points e and f in Fig. 4 do not lie within zone AB; but, since they correspond to speeds not far from 15 miles per hour, (13.0 and 16.7 m.p.h. respectively) they are there plotted in order to fill out the exhibit for the first 10 miles.

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is apparent that neither variations in car weight nor variations in speed can account for the regular decrease in resistance shown in Fig. 4. This decrease must therefore be due to the only remaining variable which exerts any important influence upon resistance, viz., journal temperature. It is therefore assumed that in Fig. 4 the regular decrease in resistance as the train progresses is due to the fact that the journal temperatures are constantly increasing and that oil viscosity and journal resistance are therefore diminishing. This assumption underlies the further discussion of this and of the following figures. The test conditions* make it difficult to directly measure the temperature of the journals in the train and the results are therefore presented in terms of distance run by the test train. The journal temperatures are intimately related to this distance unless the test is run under widely varying speeds.

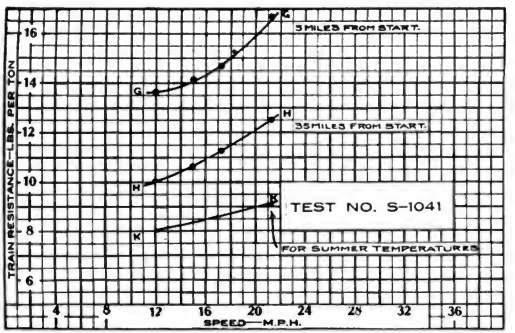

FIG. 6. SHOWING THE RELATION BETWEEN RESISTANCE AND SPEED FOR TEST 1041 AT 5 MILES AND AT 35 MILES FROM THE BEGINNING OF THE RUN

The curve CC drawn in Fig. 4 represents approximately the rate at which resistance changes with distance run, and it applies to a speed of about 15 miles per hour. It is apparent from this curve that the resistance at the beginning of the run is about 14 lb. per ton at this speed and that it constantly decreases until the train has progressed about 35 miles, at which point the

*The trains tested are freight trains of the Illinois Central Railroad, accepted as they come in the regular service. It has not proved feasible, thus far, to directly measure the temperature of any of the journals of the cars composing these trains.

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resistance reaches its minimum value of about 10.5 lb. per ton and the journal temperature reaches its maximum. Trains of like character when run at similar speeds in warm weather reach their minimum resistance within the first eight or ten miles of their run, and their minimum resistance is less than that attained in the train whose performance is exhibited in Fig. 4.

Fig. 5 also shows for this same test (1041) the decrease in resistance as the train progresses. The curve C there shown is reproduced from Fig. 4, and the additional curves A, B and D there drawn were derived by a process similar to that just explained in the discussion of Fig. 4. The curves A, B, C and D denote the approximate resistance for speeds of 21.3, 17.3, 15 and 12 miles per hour, respectively. All four curves show that the minimum resistance is reached at about 35 miles from the beginning of the run. For widely different speeds this distance would be different. Fig. 5 offers a means whereby we may determine the relation between resistance and speed at different points in the run. This relation is found in the following manner. On Fig. 5 the lines EE and FF are drawn, intersecting all four curves at points corresponding respectively to 5 and 35 miles from the start. The points at which the line FF cuts curves A, B, C and D determine four resistance values which correspond respectively to speeds 21.3, 17.3, 15 and 12 miles per hour. These corresponding values of resistance and speed constitute the co-ordinates of the four points shown on the curve H of Fig. 6 and serve to define this curve. The values corresponding to the intersections of the line EE with the four curves of Fig. 5 serve similarly to define the curve G of Fig. 6. In Fig. 6 vertical distances represent resistance and horizontal distances represent speed, the curves G, and H represent, therefore, the variations of resistance with speed for test 1041, and present train resistance curves in their usual form. The curve G shows the resistance at about 5 miles from the beginning of the run, when the journals are still cold. The curve H shows the resistance at 35 miles from the beginning when the journals have attained their maximum temperature. Fig. 6 presents the same information as is embodied in Fig. 5; but in a more familiar form. It should be recalled that Fig. 6 applies to a test made when the air temperature varied from 30° to 42° and when the wind was light. The train was composed of cars weighing, on the average, 17.2 tons.

In order to compare the resistance shown by curves G and H

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with the resistance prevailing in warm weather, the curve K is drawn in Fig. 6. This curve is derived from Fig. 1 and shows the approximate resistance in summer weather of a train composed of cars weighing 17.2 tons. Curve K is therefore comparable with either G or H. Curve H represents resistances which are approximately 25 to 30 per cent greater than those represented by curve K and we may conclude that for the train of test 1041 even the minimum resistance attained after the train had run 35 miles is about 25 per cent greater than the resistance of a similar train in warm weather. Whether the change from summer temperatures to a temperature of 30° will always result in an increase of 25 per cent in the resistance does not appear, and the data in hand do not as yet warrant generalizations of this sort. Attention is again called to the fact that the term resistance as here used means resistance on level track, and consequently a difference of 25 per cent in resistance does not necessarily require a difference of 25 per cent in tonnage rating. This statement is developed beyond.

Fig. 3 to 6 constitute what is perhaps unneeded evidence of the effect of low air temperature upon train resistance and upon tonnage rating. They show a way in which quantitative expression may be given to this effect. These four figures also serve to show the methods employed in the study of this problem which is now in progress at the University of Illinois. When this work has progressed far enough to cover all ordinary ranges of air temperature and all ordinary car weights, it may result in information which will enable tonnage reductions to be determined more systematically than seems now to be possible. It may be of interest to present a few additional diagrams touching one or two other phases of the subject.

Fig. 7 and 8 are similar to Fig. 3 and 4 and they lead to similar conclusions. Fig. 7 and 8 apply to test 1045 during which the air temperature varied from 22° to 26°, and for which the train was composed of cars averaging 49.2 tons in weight. In Fig. 7 the resistance values are plotted with respect to speed and the same difficulty of discovering any relation between resistance and speed presents itself as was presented in Fig. 3. When, however, these resistance values are plotted with respect to distance from the beginning of the run, as they are in Fig. 8, they arrange themselves in a more orderly way. All the points of Fig. 7 are plotted in Fig. 8. Points 8, 9 and

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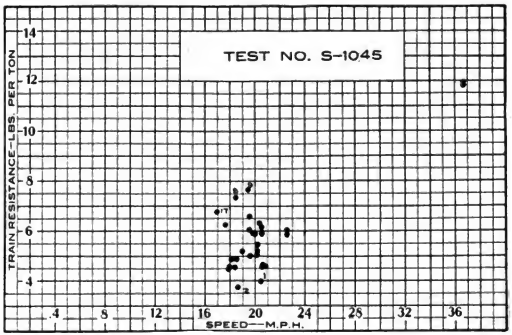

FIG. 7. SHOWING THE RELATION BETWEEN RESISTANCE AND SPEED FOR TEST 1045—AIR TEMPERATURE VARIED FROM 22° AT THE BEGINNING TO 26° AT THE END OF THE TEST

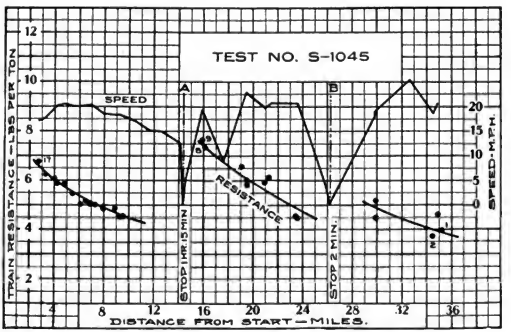

FIG. 8. SHOWING THE DECREASE IN RESISTANCE AS THE TRAIN OF TEST 1045 PROGRESSES, AND THE INFLUENCE OF STOPS UPON RESISTANCE

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17, which in Fig. 7 correspond to the highest values of resistance, fall in Fig. 8 either at the beginning of the run or immediately beyond the stop at A; whereas points 1 and 2 which have the lowest resistance values fall at the end of the run. In Fig. 8 the speed during the run is indicated by the line in the upper part of the diagram. It will be noticed that the train was brought up to a speed of about 20 miles per hour within the first three miles of the run and that the speed was thereafter maintained at approximately 20 miles, except in the immediate neighborhood of the two stops which are indicated at A and B. The speed for all but four of the points for which resistance is calculated lies between 18 and 21 miles per hour, and the speeds for these four points lie close to this range. Since the speed is so nearly uniform for all these points, its influence in modifying resistance is practically eliminated, and such changes in resistance as are indicated on the diagram are chiefly due to changes in journal temperature. At point A about 14 miles from the start the train was stopped for one hour and fifteen minutes, the air temperature at that time being 23°. Again at B, 12 miles farther along, a stop of two minutes' duration was made. It is interesting to note the effect of these stops upon the resistance. The resistance in the beginning is in the neighborhood of seven pounds per ton. It steadily decreases as the train progresses, until at the point A, where the train was first detained, it had fallen to about four or four and one-half pounds. Upon leaving A the train's speed was immediately raised to its general value of 20 miles per hour and the resistance is found to have risen again to about the same value which it had at the original starting point. From there on, the resistance again decreases steadily until the point B is reached, after which there is a slight increase in resistance due, probably, not so much to the two-minute stop as to the cooling of the journals during the considerably longer period in which the speed at this point was low, while the train was approaching and leaving B. The diagram serves well to show how important the effect of such a stop as that at A may be. If the ruling grade in this case had occurred just beyond A, it is entirely likely that the increased train resistance would have stalled the train at that point. There is no evidence in this diagram that the minimum resistance of this train at this speed is reached during the test. Indeed, if the resistance curves there drawn are accepted as correct, it seems clear that

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the stops have delayed the establishment of this minimum resistance beyond the test limits. Comparison with resistance in warm weather is therefore unwarranted.

During test 1084, the results of which are presented in Fig. 9, the air temperature varied from 1° below zero at the beginning to 5° above zero at the end of the test. These temperatures are lower than any others prevailing during the tests here discussed, and Fig. 9 is introduced primarily on that account. It exhibits the same facts as may be derived from Fig. 4 and 8 and needs but little additional comment. The speed during this test was increased from 8 miles per hour near the start to 20 miles per hour at the point A, beyond which it was maintained almost uniform at 20 miles per hour. The resistance values derived for the first 10 miles of the run are not numerous enough to offer much information. Between A and B, however, the points are more numerous and indicate clearly the usual decrease in resistance as the train progresses. The resistance, which at A is 20 pounds per ton, has decreased at B—24 miles from the start—to about 16 pounds per ton, and probably it would have continued to decrease had the test been continued beyond this point. The normal resistance in summer weather for a train of this car weight (16.5 tons), as derived from Fig. 1, is 9.5 pounds per ton. The train of this test has, therefore, a resistance 68 per cent in excess

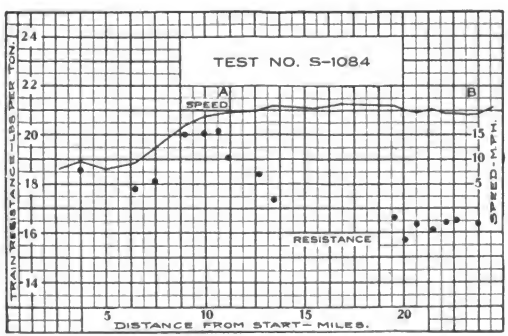

FIG. 9. SHOWING THE DECREASE IN RESISTANCE AS THE TRAIN OF TEST 1084 PROGRESSES—AIR TEMPERATURE VARIED FROM 1° BELOW TO 5° ABOVE ZERO

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of the normal, even after running 24 miles. Part of this excess is doubtless due to the fact that a strong wind prevailed during the test; most of it, however, is probably due to low temperature.

Fig. 10 and 11 apply to test 1086, during which there were very light winds and the air temperature varied between 28° and 30°. The test train was composed of cars whose weights averaged 59.5 tons. Fig. 10 shows the resistance values plotted with respect to speed, and it differs from similar preceding diagrams only in that the speeds vary throughout a greater range. This figure will be used, as have the others, to show the influence of journal temperature; but before doing so it may be of interest to show how plausibly this exhibit might be so construed as to lead to wrong conclusions.

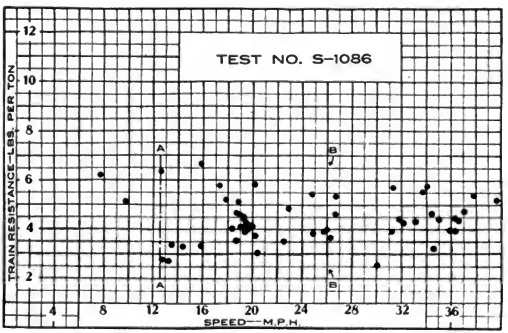

FIG. 10. SHOWING RESISTANCE AND SPEED FOR TEST 1086—AIR TEMPERATURE VARIED FROM 28° TO 30°

The diagram exhibits considerable variations in the resistance values, even at like speeds. Let it be assumed, however, that speed is the only important influence at work in causing this variation. Presupposing that no record of wind velocity is available it might seem justifiable to ascribe much of this variation to the variations in wind resistance, and also to occasional changes in such elements of resistance as flange friction. Making such allowances, the discordance among points in the diagram might appear no greater than should be expected. Such considerations might easily lead to the belief that the diagram does actually represent the true relation between average train resist-

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ance and speed, and it would therefore appear justifiable to represent this relation by a line drawn among the points of Fig. 10. An attempt to thus express the assumed relation would probably result in a horizontal straight line lying at a height corresponding to about 4.5 pounds per ton. Such a process would consequently lead to the conclusion that for this train the resistance is the same for all speeds up to about 40 miles per hour; that is, that train resistance is independent of speed. It is obvious, however, from what has preceded, that in causing the variations in resistance shown in Fig. 10, the journal temperature plays at least as important a part as the speed. Fig. 11 will make it clear that there is no warrant for the above conclusion in this case.

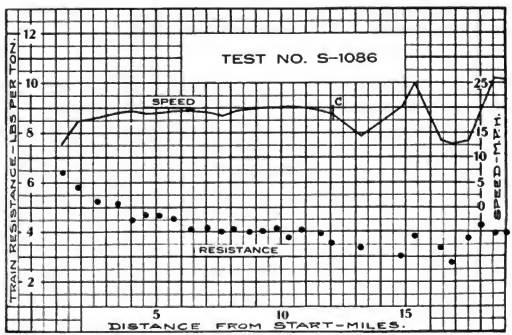

FIG. 11. SHOWING THE VARIATION OF RESISTANCE WITH DISTANCE AND WITH SPEED FOR TEST 1086

Fig. 11 comprises the points which in Fig. 10 lie between the lines A and B, corresponding to speed limits of 12.5 and 26 miles per hour. B is chosen at this point merely to reduce the length of Fig. 11. The resistance value for each point lying within this zone is plotted in Fig. 11 with respect to the distance of this point from the start. The upper line in Fig. 11 again represents the speed, which was quite uniform and near 20 miles per hour for the first 12 miles of the run—up to the point C. Beyond C the speed varied considerably. As in the tests previously discussed, the resistance decreases with great regularity during the first 12

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miles, until at C the journals have apparently attained their maximum temperature for a speed of 20 miles per hour, and the resistance has reached its minimum value for this speed. Beyond C, therefore, the influence of journal temperature upon resistance largely disappears and the resistance thereafter responds, in its variation, quite definitely to changes in speed.

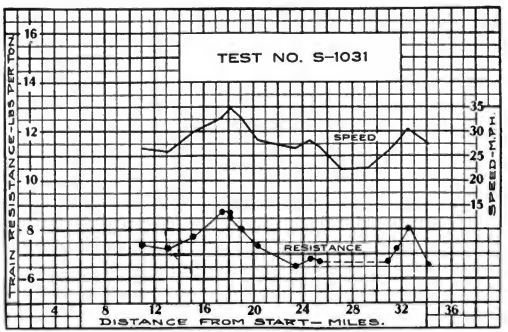

FIG. 12. SHOWING THE INTIMATE RELATION OF RESISTANCE AND SPEED AFTER THE JOURNALS HAVE BECOME WARM

Reference was made above to the definite response made by resistance to changes in speed, after the journals have become thoroughly warmed up. Fig. 12 is introduced to further illustrate this. It applies to test 1031, which was made in warm weather and which was selected on this account. During test 1031 the air temperature varied between 70° at the start and 82° at the end of the test. Within the first eleven miles the journals had assumed their maximum temperature and the record is presented only for that portion of the run lying beyond this point. As before, the upper line in Fig. 12 represents speed and the lower line represents resistance. The diagram reveals the intimate relation which exists between resistance and speed when the journals are warm. Every change in speed is closely followed by a corresponding change in resistance.

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III. The Effect of Grade on Tonnage Reductions

It was stated above that an increase in net train resistance, of say 30 per cent, due to low temperature, does not necessarily require a like reduction in train tonnage. This is due to the facts that net train resistance, which here denotes merely the resistance on level track, is not the only resistance which absorbs the tractive effort, and that the other resistances are unaffected by temperature.

The process of rating locomotives consists essentially in specifying a train whose gross resistance shall equal the available tractive effort. Since ratings are made to meet the conditions which exist at the ruling grades, this gross resistance must always consist of net resistance, as above defined, and of grade resistance.* Of these two elements the grade resistance is almost always the greater. Obviously neither air temperature nor any other external condition can affect the grade resistance, which is modified only by difference in grade. Since the larger element of gross resistance remains unaffected, the reductions in rating in cold weather need not be as great as the variations which cold weather causes in the smaller element of gross resistance; that is, in the net train resistance. Neither are these tonnage reductions the same for different grades. An example may serve to make this clearer.

Let us assume that it be required to find the summer and winter ratings for a certain class of locomotives on two divisions of a road, which we here designate as division A and division B. The ruling grade on A is one-half per cent, and that on B is one per cent. The resistance due to grade alone is 20 pounds per ton of train weight for each per cent of grade, and the grade resistance on division A is therefore 10 pounds per ton while on division B it is 20 pounds per ton. Now assume also that the net train resistance for the desired speed is 4.5 pounds per ton in summer and that in winter it is 33⅓ per cent greater, namely, 6.0 pounds per ton. We assume further that in summer the available tractive effort on grade A for the class of engines under consideration is 32,000 lb. and on grade B 30,500 lb. If the effect of cold weather upon the engine itself be assumed such as to cause a reduction of

*Acceleration and curve resistance may also be components of this gross resistance. They are, however, ignored here, since their consideration is not necessary to the argument, although their presence may modify its conclusion.

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five per cent in tractive effort, we find the available tractive effort in winter to be 30,400 lb. on division A and 28,970 lb. on division B. We have now available enough information to calculate the tonnage ratings. On division A, for example, the gross resistance in summer is 10+4.5=14.5 lb. per ton, the tractive effort is 32,000 lb. and the tonnage is consequently 32,000÷14.5=2,207 tons. The winter tonnage on division A is 30,400÷(10+6.0)=1,900 tons. The proper winter tonnage on division A is found therefore to be (2207—1,900)÷2207=14 per cent less than the summer tonnage. Similarly for division B the tonnage reduction for winter weather is found to be 10 per cent. The results of these calculations are summarized in the following table:

		Division A	Division B
Ruling Grade—per cent		½	1
Tractive Effort in Summer,	pounds	32,000	30,500
Tractive Effort in Winter,	pounds	30,400	28,970
Grade Resistance,	pounds per ton	10	20
Net Resistance in Summer,	" " "	4.5	4.5
Net Resistance in Winter,	" " "	6.0	6.0
Gross Resistance in Summer,	" " "	14.5	24.5
Gross Resistance in Winter,	" " "	16.0	26.0
Tonnage in Summer,	tons	2,207	1,245
Tonnage in Winter,	"	1,900	1,115
Tonnage Reduction,	per cent	14	10

It is apparent from these calculations that an increase in net resistance of 33⅓ per cent necessitates a reduction in rating on division A of only 14 per cent and on division B this reduction need be only 10 per cent. Not only are the tonnage reductions in both cases considerably less than the difference in net resistance, but the reductions are different on the different grades. The greater grade requires the smaller tonnage reduction. If the ruling grades on a particular road do not differ greatly on the different divisions, it would be an unnecessary refinement of practice to discriminate between divisions in establishing tonnage reductions for winter weather. If, on the other hand, a road runs in both level and mountainous country, it is not only logical but economical to make such distinctions. The information at hand concerning current practice indicates that these facts have received little consideration, or at any rate, no application in the establishment of certain existing tonnage rating systems. On other roads, however, the facts are duly recognized and embodied in their rating practice.

There are a few roads operating almost exclusively in mountain territory which find it unnecessary to make reductions in rating for low temperatures. The ruling grades on these

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roads are, of course, heavy. The foregoing example illustrates how the effect of heavy grades may disguise and almost nullify great variations in net resistance, and it offers, therefore, some justification for the practice which ignores distinctions between summer and winter ratings in such territory.

These facts serve also to show the necessity for care in adopting on one road the practice which has proved satisfactory on another. Unless the ruling grades are nearly alike, the system of tonnage reductions which has proved itself satisfactory on one road ought not to be transplanted to another without due consideration of these facts, even though the weather conditions are identical.

IV. A Summary of Current Practice

In connection with this investigation, a considerable amount of information has been collected from the railroads of the country concerning their tonnage rating practice. The attempt has been made to summarize this information and present it in the table which is here included, in the expectation that it would be useful to have such information assembled in somewhat compact form. It is believed that the table fairly represents, in most cases, the practice of the various roads as stated by their own officers. It has, however, been difficult occasionally to force into the form and limits of the table all the information available, and in a few cases the tabular statement scarcely represents all the facts. It is difficult, for example, to present in tabular form the limitations placed by some roads upon the application of their general practice. It is hardly possible to indicate in the table the degree of authority given on these roads to trainmasters and dispatchers, under which they may vary from the usual practice.

The roads are arranged in the table in the order of the air temperature limits which determine the normal rating and which appear in the first column. This arrangement was adopted because it makes easier the direct comparison of figures appearing in the later columns. At the same time, it brings together roads which operate in very different territory and under very different weather conditions and these facts should be borne in mind in making comparisons. Examination of the table makes it evident at once that there is great diversity of practice. Not only are different tonnage reductions made for similar temperatures,

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but the range in temperature which is considered to warrant tonnage reduction varies from a few degrees to 30 or 40 degrees. Some roads have only one rating schedule in addition to their normal schedule; others operating under weather conditions not radically different have as many as ten additional schedules. Most of the differences in practice are, however, not surprising when it is considered that the roads included, represent practically the entire United States and Canada and represent, therefore, the greatest variety in weather conditions and topography. Most of the differences in practice disclosed by the table are quite sufficiently explained by the differences in the weather conditions prevailing in the territory served.

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